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BASE BLEED SOLID PROPELLANTS CONTAINING THERMOPLASTIC ELASTOMERS AS BINDERS

W. KLÖHN and A. RASSINFOSSE
Fraunhofer-Institut für Treib- und Explosivstoffe, Pfinztal (F.R.G.)
International Industrial Products, Bruxelles (B)

ABSTRACT

For the manufacture of base bleed gas generator propellant charges, propellants were developed which contained as binders thermoplastically moldable elastomers of the butadiene- and isoprene-styrene three block copolymer type.

The present paper gives a description of the production of propellant granules from the oxidizer and the copolymer as well as of the compression molding of this material to form base bleed propellant charges.

Moreover, reference is being made to the procedure of insulation of propellant charges with a thermoplastic elastomer of the same type.

This new type of solid propellants is described by its mechanical, ballistic and physical properties and by its safety aspects.

Finally, some considerations are being made with regard to a production of these propellants on a commercial scale.

INTRODUCTION

For increasing the range of artillery projectiles, base bleed gas generators have gained a considerable importance over the last few years.

The principle by which a base bleed generator fuctions may be described in that the gases escaping from the gas generator fill the vacuum produced behind the projectiles when in flight, thus contributing to a reduction of the base drag. However, the projectile receives no additional propulsion by these gases escaping in the subsonic range, such as is the case with rocket-assisted projectiles.

The possibilities of reducing the base drag according to K. Andersson and Colleagues (ref. 1) are summarized in Fig. 1.

Trials on the effectiveness of base bleed gas generators have principally been performed by Swedish researchers (ref. 2-5).

Fig. 2 shows the arrangement of a base bleed gas generator propellant charge with an interior burning configuration inside an artillery projectile of the 155 mm caliber.

RESULTS

Work Concept

For the manufacture of the propellants, a new procedure has been developed and tried out whereby compression molding takes place in a pressing procedure.

The following components were used to develop the propellants:

- Ammonium perchlorate
- Nitroguanidine
- Thermoplastic rubber
- Additives

As the base bleed gas generators function with a subsonic escape flow, the pressure in the burning chamber and thus also the burning rate as well as the mass flow decrease with the rising trajectory height.

Values $<$ 1 mm/sec were aimed at as desirable burning rates at ambient pressure. The standard of the mechanical properties of the propellant in the range of - 40 to + 50^{o} C (- 40 to + 122^{o} F) had to reach values which were sufficient to avoid the formation of cracks or even destruction of the propellant charge resulting from the shock experienced upon firing of the cannon.

In view of these extreme loads, selection of the proper insulation with its reliable adhesion to the propellant charge is also of considerable importance. These requirements are also optimally fulfilled by using a thermoplastic rubber.

Binder Systems

The elastomers provided for the propellants as binders consist of known compounds of the styrene-butadiene- and styrene-isoprene- type called three block copolymers.

In the case of the ABA-type three block copolymers, the outside A blocks consist of styrene segments exhibiting a thermoplastic characteristic and whose glass transition temperatures are situated in the region of $>$ 100^{o} C (212^{o} F).

On the other hand, the center block B consists of rubber elastic polybutadiene- or polyisoprene segments with glass transition temperatures of $<$ - 65^{o} C (- 85^{o} F).

Sections of block copolymers which are sufficiently long are intolerant to each other and attempt to separate. The polystyrene phase present in small quantities therfore forms aggregates, the so-called domains, which are embedded in the continous polybutadiene- or polyisoprene phase (Fig. 3) (ref. 6).

These domains may be viewed as cross linking points for the elastomer chains. This thus means that they play a similar role to that of sulphur bridges in the conventional vulcanisation of rubber.

The domains of the polystyrene phase become soft, however, if the processing temperature rises beyond the glass transition point. The entire material then exhibits a thermoplastic behaviour and may be processed in presses (pressure-setting) extruders. After cooling down to temperatures below the glass transition point of poly-

styrene, the domains revert to the shape of spheres or rods and thus reacquire their rubber-elastic properties.

Manufacture of Base Bleed Propellants (ref. 7-8)

Manufacture of propellant in granular form. In order to obtain base bleed propellant charges through pressing into molds, it is first of all necessary to produce a granule in which all components are distributed homogenously and inseparably.

As the binder is available in the form of solid granules, the filling components must be mixed with this binder in a procedure using solvents.

To do this, a thermoplastic rubber such as, for example, Kraton[R] was previously put into a horizontal kneading machine, and the additives such us plasticiser, wetting agent, stabilizer and bonding agent, dissolved in trichlorethan, were then added. After a short mixing period at temperature of approx. +6o^0 C (+140^0 F) a paste-like mass, in which the binder was homogenously dissolved (Fig. 4), was produced.

With propellant masses of 50 kg (110.1 lbs), this mixing procedure was terminated after 40 minutes and it was possible to distill the solvent under vacuum.

Thanks to the "scissor" effect of the interlocking blades in the mixer, the mass was broken up into granules having grain sizes $<$ 2.0 mm. These granules were then freed of residual solvent by subsequent drying. The residual humidity was in the region of values $<$ 0.1 %.

The processing method just described for preparing the propellant components in granular form presents a series of advantages:

- Manufacture of granules and homogenous distribution of components within a short period (time saving),
- A separate drying procedure for the raw materials used is no longer necessary, as any remaining humidity can be distilled off azeotropically with the solvent,
- Air conditioning of the work rooms is no longer required, as experience up till now has shown that granules are very insensitive to humidity,
- The possibility of manufacturing large quantities of granules with an unlimited shelf life,
- The possibility of mixing up large batches in order to obtain high uniformity/homogeneity, and
- The facility of exact granule dosage, thus providing for a very low mass deviation of the propellant charges.

The manufacture of insulation and propellant charge by means of a compression molding procedure. As a propellant insulation material, a similar but harder (by adjustment) thermoplastic rubber was used.

The granular polymer material required for the insulation layer was filled into a special press mold and subjected to molding after heating to +120^0 C (+248^0 F)

(Figs. 5-6), so that the melted mass between the inner wall of the mold and the plunger completely filled out the remaining gap of 2 mm. After cooling to room temperature, it was possible to obtain an insulation layer in the form of a half shell (Fig. 7).

The propellant granules were filled into the insulation layer thus obtained and pressed at 120^0 C under vacuum, this time using a molding plunger of a different shape. The binder of the propellant granules melts together and with the insulation to form a joined body possessing great adhesibility (Fig. 8-9).

After cooling once more, the finished half of the propellant charge can be pushed out of the mold (Fig. 10).

Properties. The mechanical properties of different base bleed propellants in the temperature range of - 40^0 C through + 50^0 C have been summarized in Fig. 11.

The brittle point was determined in high speed tensile tests with cross head rates of 1.5 m/sec as depending upon temperature (Fig. 12). The maximum of strength at break is defined as the brittle point.

The burning rates obtained from tests in the original burning chamber may be seen in Fig. 13 and 14.

The propellant charge made up of two half sections was preferred as a propellant configuration (Figs. 15-16).

The burning properties of base bleed propellants under vacuum were obtained from isolated propellant disks with a 50 mm diameter (1.968") and a length of 10 mm (0.393") (Fig. 17).

Finally, in Fig. 18, the burning rate of a propellant in the transition from the subsonic to the hypersonic escape flow is given. With area ratios in the region of $40 > K > 160$, instabilities such as shuffing may occur during the course of burning.

A list of further properties may be seen in Fig. 19.

Discussion of properties. In the case of the base bleed gas generator propellants presented in this study, it is our opinion that steps have been taken for the first time to manufacture viscoelastic solid propellants via the use of thermoplastic elastomers.

The viscoelastic properties of the propellants meet the requirements made of a propellant which can be subjected to high loads.

Under extreme test conditions (1.5 m/sec), a brittle point of - 45^0 C (- 49^0 F) was obtained in high speed tensile tests. These temperatures are far above those of known gun propellants.

The burning rate of the propellants fulfilled the requirements demanded of them at values < 1.0 mm/sec. In actual flight tests after firing from a cannon, the gas

generators functioned for approx. 35 seconds. The previously obtained increases in range using 155 mm projectiles amounted to approx. 30 %.

In the tests performed, it was possible to achieve stable burning in the region of 200 to 2,000 mbar.

The other properties are comparable to those of we l known composite solid propellants.

Industrial production. The procedure described has been adapted to the industrial scale with considerable simplifications.

For example, it was possible to manufacture the insulation sections on transfer molding machines in accordance with a procedure for thermoplastics. The manufacture of granules can also be rationalized by processing with a thermoplastic procedure instead of using solvents.

Initial trials have provided excellent results, as the compounding of the solids with the thermoplastic elastomers was undertaken in a contious mixer through the phase of the melted elastomer (Fig. 20). This step in the process saves a series of work processes, as the granules can thus be obtained in a ready-to-use state. Furthermore, a granular product with a very uniform grain size was obtained.

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FIGURES

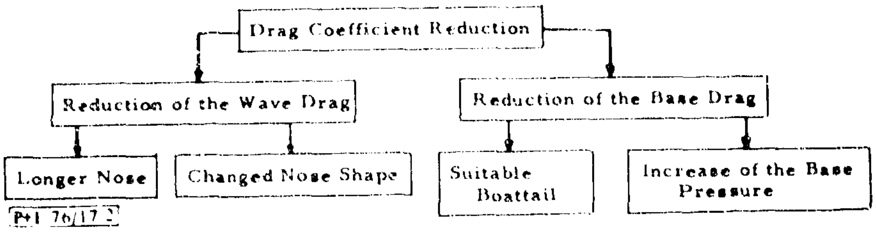

Fig. 1: Drag coefficient reduction according to ref. 1

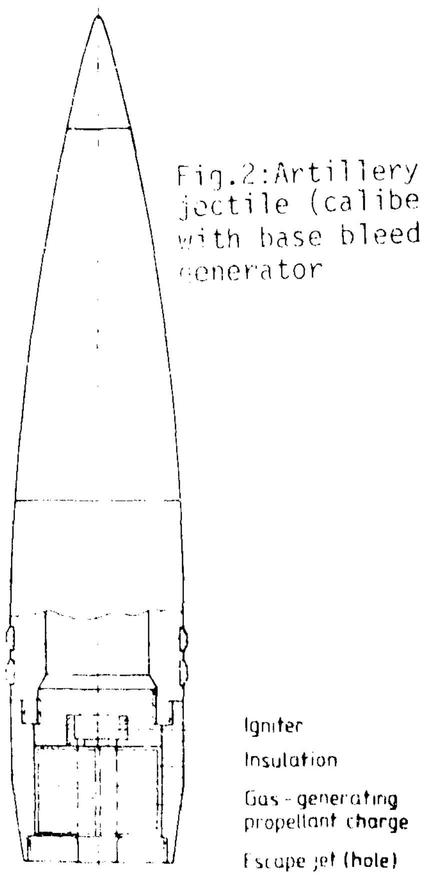

Fig.2:Artillery projectile (caliber 155mm) with base bleed gas generator

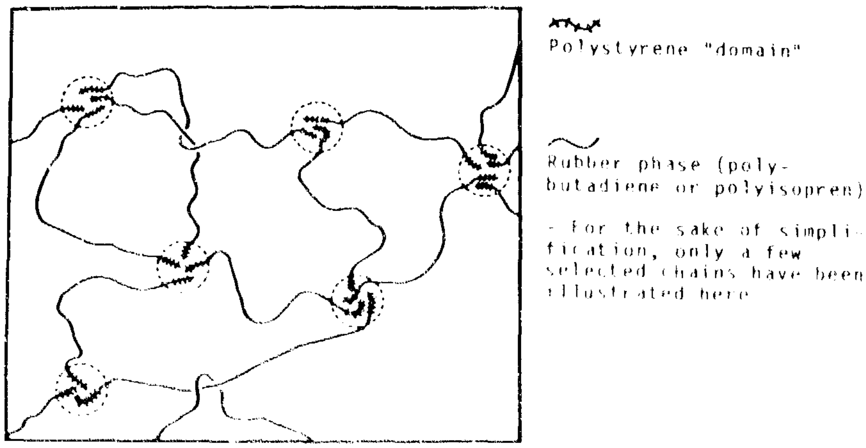

Fig. 3: Position of phases in SBS/SIS rubber types in accordance with ref. 6

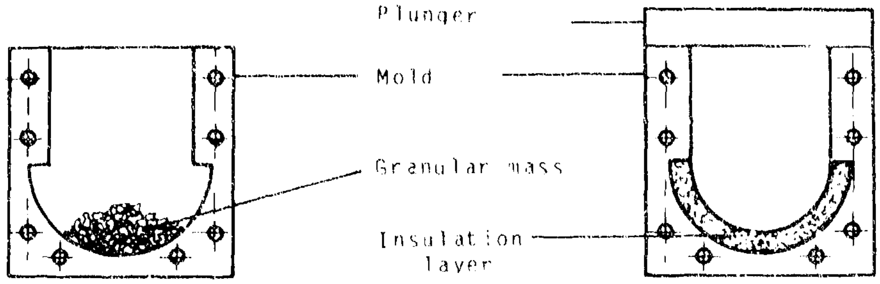

Fig. 5: Compression molding of insulation layer

Fig. 4: Manufacture of propellant granules
in the horizontal kneading machine

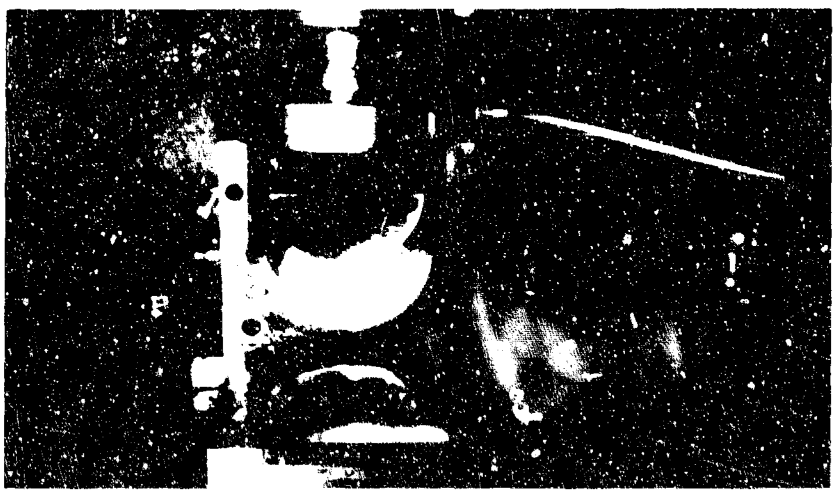

Fig. 6: Manufacture of insulation half shell
from thermoplastic elastomers

Fig. 7: Molded half shell of insulation

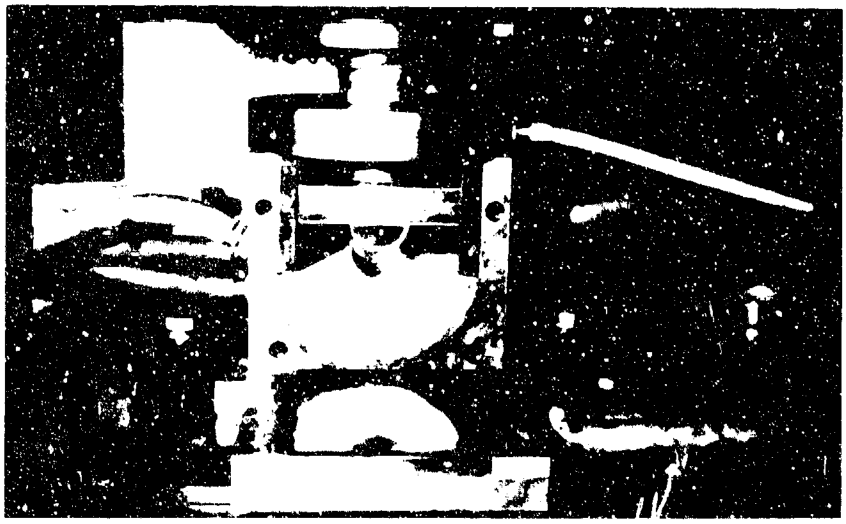

Fig. 9: Manufacture of base bleed propellant charges

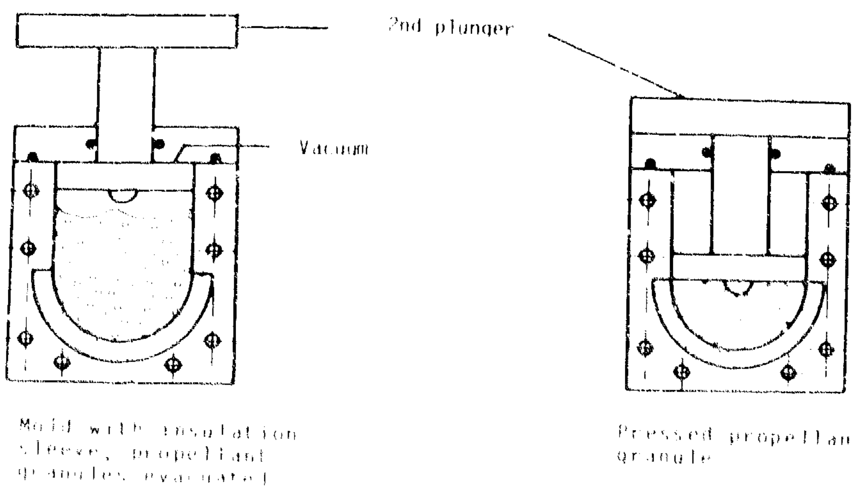

Fig. 8: Compression molding of propellant charge

Temperature	-40°C	(-40°F)	-10°C	(-14°F)	+20°C	(+68°F)	+50°C	(+122°F)
Propellant No.	$\frac{\sigma_R}{bar}$	$\frac{\varepsilon_R}{\%}$	$\frac{\sigma_R}{bar}$	$\frac{\varepsilon_R}{\%}$	$\frac{\sigma_R}{bar}$	$\frac{\varepsilon_R}{\%}$	$\frac{\sigma_R}{bar}$	$\frac{\varepsilon_R}{\%}$
171	15,4	22,5	3,7	68,7	2,4	>125	0,8	58,5
182	20,9	96,0	6,1	123,0	4,2	>125	2,3	32,3
186	3,0	>125	-	-	1,2	>125	1,0	83,0
190	11,6	20,3	3,1	>125	2,8	>125	2,0	34,7

Fig. 11: Mechanical properties of base bleed propellants (crosshead rate: 50 mm/min)

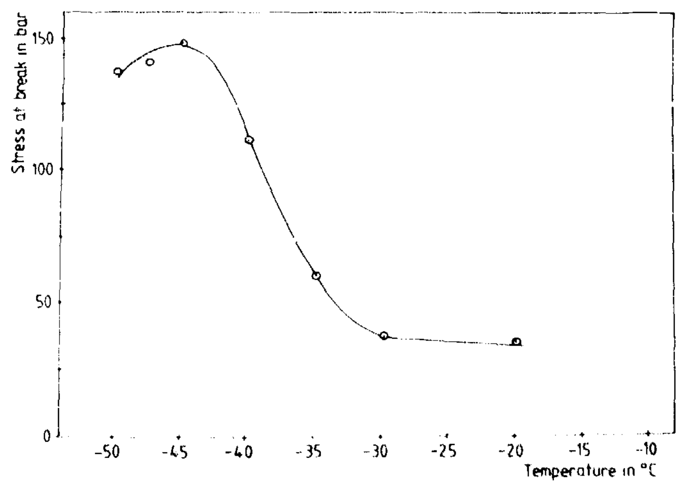

Fig. 12: High speed tensile tests of base bleed propellants (crosshead rate = 1,50 m/s)

Fig. 10: Base bleed propellant charge, half section

No.	Propellant	$\frac{p_{Initial}}{mbar}$	$\frac{p_{Final}}{mbar}$	$\frac{t}{s}$	$\frac{r}{mm/s}$
1	CBB 79/L1	65	27	38,7	0,94
2	CBB 79/L1	56	24	38,3	0,95
3	CBB 79/L4	45	21	38,4	0,94
4	CBB 79/L4	59	22	38,2	0,95

Propellant mass = 1420 g
Ambient pressure = 1006 mbar

Fig. 13: Burning rate of base bleed propellant charges in burning chambers with a sub-critical mass flow

Temperature	-40°C (-40°F)	+20°C (+68°F)	+50°C (+122°F)
Propellant No.	$\frac{r}{mm/s}$	$\frac{r}{mm/s}$	$\frac{r}{mm/s}$
185	0,865	0,962	0,988
194	0,904	0,988	1,024

Lenght of propellant charge (w/o insulation)	106,0 mm
Diameter of propellant charge (w/o insulation)	116,0 mm
Slot width	3,0 mm
Interior bor of propellant charge	43,5 mm
Web thickness	36,0 mm

Fig. 14: Burning rate of base bleed propellant charges in burning chambers in dependance upon temperature

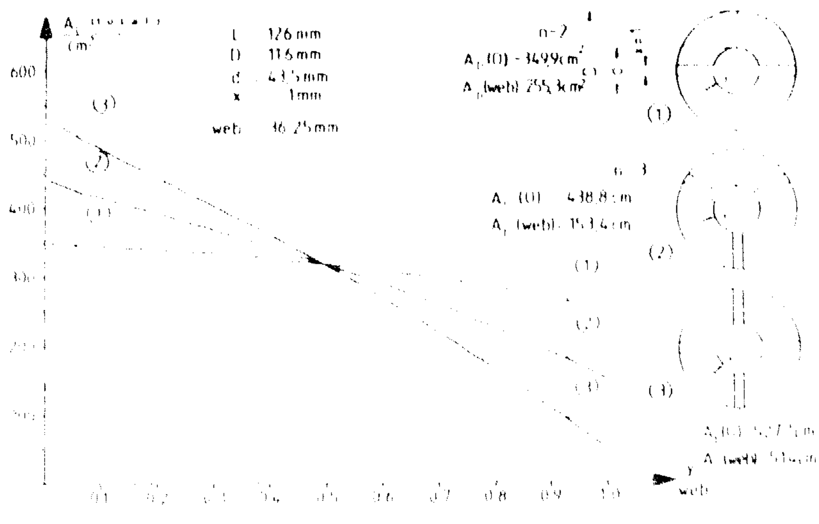

Fig. 15: Change of burning surface at different propellant charge geometries

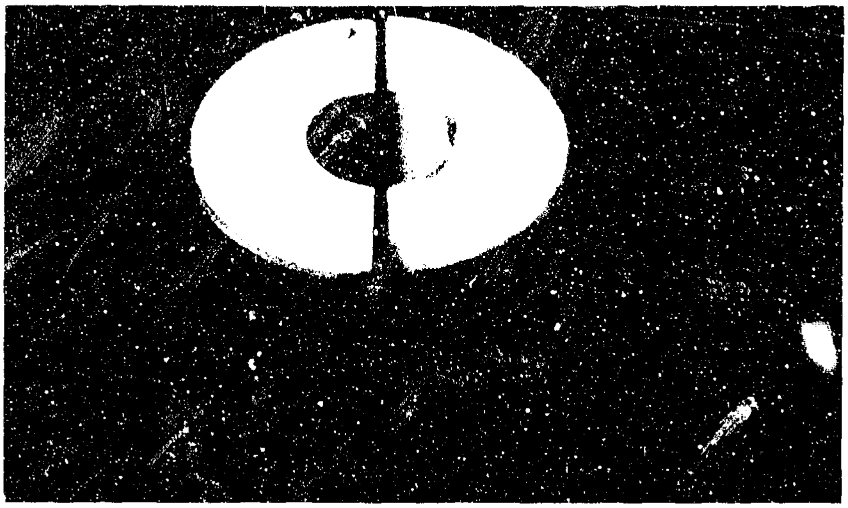

Fig. 16: Base bleed propellant charge

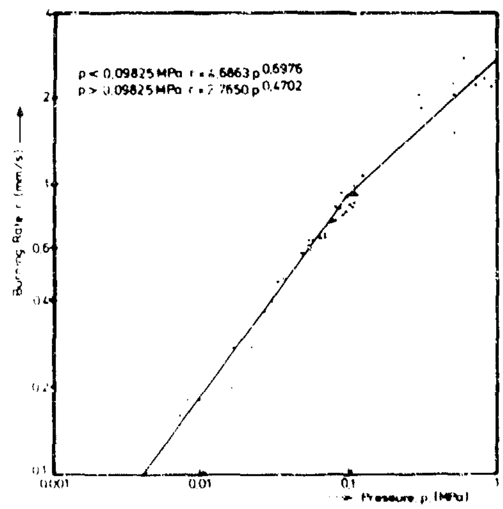

Fig. 17: Burning properties of base bleed propellant charges under vacuum

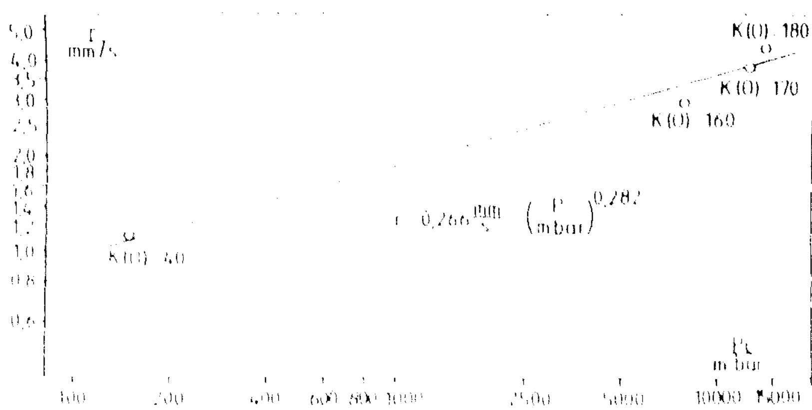

Fig. 18: Burning rate of base bleed propellant charges at the transition between subcritical and hypercritical escape flow

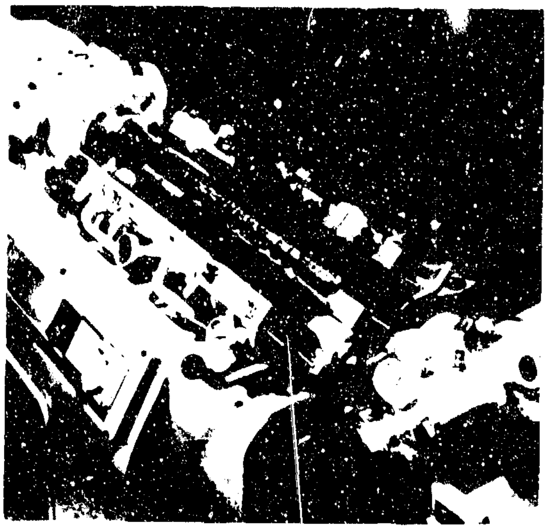

Fig. 20: Continous mixer for production of base bleed granules (systeme Buss)

Deflagration temperature (20° C/min)	°C °F	276 529
Weight loss after 40 days / +90°C (+194°F)	%	0,2
Dutch-Test Weight loss 8-72 hrs +105°C (+221°F)	%	0
Density	g/cm^3	1,55
Sensitivity to impact	Nm	3,40
Sensitivity to friction	N	160
Shore hardness		A 75
Heat of explosion	J/g	3480

Fig. 19: Different properties of base bleed propellants